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(71) Applicant: ICO Services Ltd.
Hammersmith, London S6 9BN (GB)

(72) Inventor: Wyrwas, Richard
Southgate, London N14 6LN (GB)

(74) Representative: Geary, Stuart Lloyd et al
Venner, Shipley & Co.,
20 Little Britain
London EC1A 7DH (GB)

(54) Diversity communication system

(57) In a communication system, a base station (1) transmits to a mobile station (5) in different channels. One channel is relayed to the mobile station (5) by a first satellite (3) and the other is relayed by a second satellite (4). The mobile unit (5) compares the qualities of the signals relayed by the satellites (3, 4) and transmits back to the base station (1) using the satellite (3, 4) providing the best quality signals. The use of satellite links is not essential.

The system has the advantages of diversity communication without increasing power demand at the mobile station.

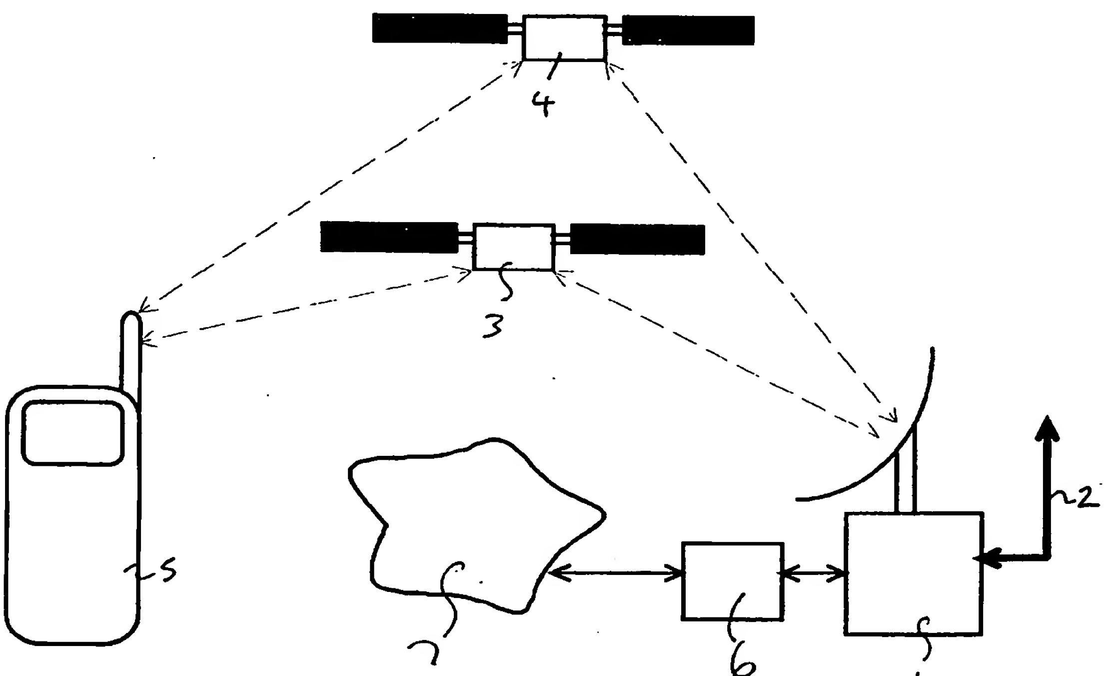

Fig. 1.

EP 0 837 568 A2

Description

The present invention relates to a method of diversity communication comprising contemporaneously transmitting signals, including at least a first user-generated information signal, from a first station in a plurality of forward channels, and transmitting a second user-generated information signal from a second station to the first station in a channel selected from a plurality of return channels on the basis of the quality of signals received in said plurality of forward channels. The present invention also relates to a base station comprising first receiving means for receiving a first user-generated information signal from a user terminal, transmitter means for contemporaneously transmitting a plurality of signals, including the first user-generated information signal, in a plurality of channels, and second receiving means

In communication systems, particularly those where one station is mobile, the quality of signals received from a channel can vary from time to time, sometimes dropping to the point where a signal becomes unusable due to noise or even disappears. A known solution to this problem is to transmit the same information over two or more channels. The likelihood of the signals in all of the channels being unusable at the same time is much lower than the likelihood of one channel being unusable. The likelihood is further reduced if the physical properties, e.g. carrier frequencies or paths, of the channels differ significantly.

In is known for a base station and a mobile system to transmit in two or more manners. Since substantially the same power must be radiated for each manner of transmission in such a system as would be radiated for the single manner used in a simple system, the power requirements of the stations are increased when diversity is employed. With modern low-power signal processing circuitry, the extra power required by the station's rf power amplifier can almost double the power consumption of a station as a whole even when using only two-fold diversity. This problem is particularly acute in the case of battery-powered equipment such as hand-held mobile telephones.

Examples of communication using diversity as disclosed in GB-A-1088261 and GB-A-990139.

It is an aim of the present invention to overcome this problem.

A method according to the present invention is characterised in that the forward channels are respectively associated with different free-space paths, and the return channels are respectively associated with the free-space paths and are monitored contemporaneously at the first station for the second user-generated information signal. The second station transmits on fewer channels than the first station. In the case where the second station transmits on only one channel, the benefits of diversity can be substantially achieved without the penalty of increased power consumption at the second station. It is also to be noted that the present invention makes use of different free-space signal paths. This is particularly advantageous where one or both of the stations are moving.

In the present application, "channel" means an agency of communication having a discrete set of physical characteristics. Examples of such characteristics are carrier frequency, polarization, timing, medium, geographical route of a signal path. In a simple case, a channel may consist of a band of frequencies in the radio spectrum. However, two channels may occupy the same band of frequencies but occupy discrete time slots. A channel may also make use of a plurality of bands of frequencies at the same time, at different times or in different locations, e.g. the input and output carrier frequencies of a repeater. In a bidirectional channel, the channel may be substantially the same in both directions. However, sub-channels used for the two directions could be very different, for example one may use a low frequency carrier and the other may use a very high frequency carrier.

In the present application, "user-generated information signals" means signals conveying information which a user, e.g. a telephone subscriber, wishes to transmit as distinct from signals concerned with the management of a communications system.

User-generated information signals comprises speech signals, facsimile signals, e-mail signals, data file signals, video signals but are not limited thereto.

The signals transmitted by the first station may be routed via respective repeaters. Preferably, the repeaters are carried by respective satellites. More preferably, the satellites orbit in non-geostationary orbits.

Preferably, a plurality of communications channels are employed and each communications channel comprises a first sub-channel, providing a forward channel, and a second sub-channel following a substantially reciprocal physical path, providing a corresponding return channel. More preferably, such a method comprises transmitting the same user-generated information signal in the first sub-channel of each communications channel, determining at the second station which first sub-channel provides the best quality link from the first station and transmitting the second user-generated information signal from the second station to the first station using the second sub-channel corresponding to the first sub-channel determined to provide the best link from the first station.

Preferably, each sub-channel comprises a slot within each frame of a TDMA communications system. The channels or sub-channels may also be frequency multiplexed.

Preferably, during one frame period, the second station monitors two of said first sub-channels, determines which sub-channel provides the best link from the first station and then transmits a user-generated information signal in the time slot of the second sub-channel, corresponding to the first sub-channel which has been deter-

mined to provide the best link from the first station.

In an alternative embodiment, the first station transmits reference signals, e.g. pulses, in dedicated channels. The dedicated channels are similar enough to channels used for user-generated information that the second station can use the relative qualities of the pulse signals to select an appropriate channel on which to transmit user-generated information. The first station would respond by making its next transmission in the channel in which it receives user-generated information from the second station.

A base station according to the present invention is characterised in that the transmitter means is configured for transmitting said plurality of signals via respective free-space paths, the second receiving means is configured for contemporaneously receiving signals in a plurality of channels via respective ones of said free space paths, and means is provided for outputting a return user-generated information signal, derived from signals received by the second receiving means, to said user terminal.

Preferably, the transmitting and second receiving means are adapted for TDMA communication.

Preferably, the base station transmits the same user-generated information in each of said plurality of channels.

The base station may combine the signals received from said plurality of sub-channels to produce the output return user-generated information signal. Preferably, however, the base station selects one of said channels on the basis of the presence or absence of an information signal. This may be performed on the basis of bit error rate values or signal-to-noise ratios.

Preferably, a such a base station is incorporated with a transceiver into a communications system. The transceiver will comprise receiver means for receiving signals in a plurality of channels, means for analysing received signals to generate respective received signal quality signals, transmitter means, and control processor means for controlling the receiving means and the transmitter means, wherein the control processor means includes memory means programmed with a control program, the control processor means being operable according to the control program to configure the transmitter means to transmit on a channel selected on the basis of the quality of the signals received by the receiving means.

Preferably, the control program is such that the control processor means compares the quality of the signals received in a plurality of TDMA slots and controls the transmitter means to transmit in a slot selected on the basis of quality of said received signals.

Preferably, the control program is such that the receiver means is retuned between two TDMA slots.

Preferably, the means for analysing received signals includes signal processing means for determining a bit error rate for a received signal and generating a corresponding bit error rate signal as said quality signal.

Preferably, the tranceiver means comprises a mobile telephone.

Embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows the main elements of a satellite-based mobile telephone system according to the present invention;
Figure 2 illustrates the allocation of channels to the satellites shown in Figure 1;
Figure 3 is a block diagram of the mobile telephone of Figure 1;
Figure 4 is a timing chart illustrating the operation of the mobile telephone of Figure 3; and
Figure 5 is a block diagram of the satellite access node of Figure 1.

Referring to Figure 1, a satellite access node (SAN) 1 is connected to other SANs and administrative centres by a high-speed terrestrial data network 2. Two satellites 3, 4 carry transponders so that the SAN 1 can communicate with a mobile telephone (UT) 5. The satellites 3, 4 are members of a constellation of similar satellites in non-geostationary orbits. The SAN 1 is further connected to a gateway (GW) 6 to the terrestrial public communications networks, e.g. the public switched telephone network (PSDN) and the integrated services digital network (ISDN).

The present invention is concerned primarily with the SAN to UT link. Therefore, the architecture of the rest of the satellite telephone system will not be described further. However, further information can be obtained from "Satellite Communications Systems", 2nd Ed., Maral, G. and Bousquet, M., Wiley 1993 (ISBN 471 93032 6).

The SAN 1 to satellite 3, 4 uplinks are located in a band in the region of 5GHz and the corresponding downlinks are in a band in the region of 7GHz. The satellite 3, 4 to UT 5 downlinks are located in a band in the region of 2.1GHz and the corresponding uplinks are in a band in the region of 1.9GHz.

Each satellite 3, 4 has a plurality of redirectable antennas. The antennas are controlled such that the footprint of each will remain fixed on a particular geographical area or "cell" as the satellite passes from horizon to horizon. Each "cell" is covered simultaneously by both satellites 3, 4. As a satellite 3, 4 approaches the horizon, its antennas are redirected to provide coverage of an adjacent region while another satellite takes over the region being left. Each antenna is allocated different frequencies to those allocated to antennas covering neighbouring areas. Although only a relatively small number of frequencies are used by each antenna, the number of channels is increased by use of a TDMA scheme as illustrated in Figure 2.

Referring to Figure 2, the link from the SAN 1, via the first satellite 3, to UTs is provided by three sub-bands

b_{11}, b_{12}, b_{13}. The corresponding UT-to-SAN link is provided by three sub-bands b_{21}, b_{22}, b_{23}. Each TDMA frame is divided into four time slots t_1, t_2, t_3, t_4 which are used by respective channels. For a given channel the SAN-to-UT link uses one time slot, e.g. t_1 in one of bands b_{11}, b_{12}, b_{13}, and another time slot, e.g. t_3 in one of bands b_{21}, b_{22}, b_{23}, is used for the UT-to-SAN link. It is preferred that the UT-to-SAN and SAN-to-UT links, used by one channel, do not use the same time slot.

Communication between UTs and the second satellite 4 is similarly arranged using sub-bands b'_{11}, b'_{12}, b'_{13} and b'_{21}, b'_{22}, b'_{23}.

"Sub-band" herein refers to the sub-bands in both the SAN-to-satellite link bands and the satellite-to-UT bands.

Each SAN-to-UT and UT-to-SAN link combination of the first satellite 3 is paired with a SAN-to-UT and UT-to-SAN link combination of the second satellite 4. In extsblishing these pairs, it is preferred that no time slot is used simultaneously for two SAN-to-UT links. For example, an acceptable link pair would comprise b_{11}-t_1, b_{21}-t_3, b'_{12}-t_2 and b'_{22}-t_4. Each such link pair is used by a different channel. For transmissions to the UT 5, the same information is transmitted in both SAN-to-UT links and, for transmissions from the UT 5, one of the corresponding UT-to-SAN links is selected.

Communication between the SAN 1 and the UT 5 will now be described using, by way of example, the link pair comprising b_{11}-t_1, b_{21}-t_3, b'_{12}-t_2 and b'_{22}-t_4.

During set up of a call between the UT 5 and another subscriber via the SAN 1, during handover between cells and during handover between satellites, the satellite network control system allocates a channel, i.e. the link pair, to be used between the SAN 1 and the UT 5. The other subscriber may be the user of another UT, the user of a telephone connected to the PSTN, the user of a terrestrial cellular telephone etc.

During communication from the other subscriber to the UT 5, the SAN 1 transmits the information signals, generated by the other subscriber, in b_{11}-t_1 and b'_{12}-t_2. The UT 5 listens for both transmissions and determines which provides the best quality link from the SAN 1. If the UT 5 determines that the transmission in b_{11}-t_1 is the better, the information signal generated by the UT's user is transmitted only in b'_{12}-t_2. However, if the converse is the case, the UT 5 transmits only in b'_{22}-t_4. The SAN 1 listens for transmissions in both b'_{12}-t_2 and b'_{22}-t_4, determines which slot contains a user-generated information signal and outputs the user-generated information signal for transmission to the other subscriber.

The structure and operation of the UT 5 will now be described.

Referring to Figure 3, the UT 5 comprises a controller 51, a digital frequency synthesizer 52, an RF/IF module 53 including front end, IF, modulator and RF power amplifier circuitry, a digital signal processing (DSP) module 54, an audio module 55, a user interface module 56 including a display and a keypad, an antenna 57, a microphone 58 and a loudspeaker 59. The operation of the UT 5 is controlled by the controller 51 in dependence on a program stored therein, user commands input my means of the user interface module 56 and control signals received from the SAN 1 in a control channel.

The frequency synthesizer 52 is linked to the controller 51 and receives frequency setting commands therefrom. The frequency synthesizer 52 responds to these commands by outputting a sinewave signal to the RF/IF module 53. This sinewave signal is used either to provide a carrier for transmission or a local oscillator signal for reception.

Signals received by the receiver module 53 are demodulated and output to the DSP module 54. The DSP module 54 performs decoding and time expansion of the received signal and, if the signal is an information signal, applies the decoded signal to the audio module 55 which amplifies it and applies it to the loudspeaker 59. The DSP module 54 also outputs a bit error rate (BER) value for the currently received signal to the controller 51.

Speech signals sensed by the microphone 58 are amplified by the audio module 55 and applied to the DSP module 54. The DSP module 54 time compresses and error-correction encodes the speech signal. The resultant signal is applied to the RF/IF module 53 where it is used to modulate the carrier from the frequency synthesizer 52.

Referring to Figure 4, time is shown by the vertical axis and the various processes carried out by the DSP module 54 and the controller 51 are distributed along the horizontal axis.

Process 1 is performed by the DSP module 54 and comprises digitizing speech sensed by the microphone 58 and storing the resultant digital data. This process last for the duration of one TDMA frame and is repeated for each TDMA frame.

Process 2 is also performed by the DSP module 54 and comprises coding the digitized speech, produced in the preceding frame, and storing the resultant signal. The coding enables one frame's worth of speech to be transmitted in one slot and also adds error correction, for example Viterbi coding.

In process 3, the controller 51 outputs frequency control data to the frequency sythesizer 52 so that the RF/IF module 53 tunes to the frequencies of the two slots used by the channel/link pair allocated to the UT 5. The DSP module 54 receives demodulated digital signals, received by the RF/IF module 53. The incoming signals are error-correction coded and the DSP module 54 decodes the incoming signals to produce time-compressed, error-corrected audio data signals and a value for the BER of the incoming signals. The BER values are sent to the controller 51.

Process 4 is performed by the controller 51 and comprises determining the lower of the two BER values.

In process 5, the controller 51 instructs the DSP module 54 to expand the compressed audio data, received in the preceding frame and to which the lower

BER relates. The DSP module 54 converts the digital audio signal to an analogue signal and applies it to the audio module 55 for output to the loudspeaker 59.

In process 6, the controller 51 instructs the DSP module 54 to output coded speech signals to the RF/IF module 53 for transmission to the SAN 1. The coded speech is transmitted in the band/slot combination paired with that producing the lower BER in the preceding frame. The controller 51 also applies the appropriate frequency control data to the frequency synthesizer 52.

The SAN 1 will now be described in more detail.

Referring to Figure 5, the SAN 1 comprises a network interface 11 providing an interface to the high-speed terrestrial network 2, a modulator/power amplifier system 13, first and second feed units 14, 15, a demultiplexer 17, a signal processing unit 18, a controller 19 and first and second dish antennas 20, 21.

The interface 11 receives information signals from the high-speed terrestrial network 2 and reformats them from transmission to UTs. The information signals belong to different calls being routed through the SAN 1. The interface 11 combines the data of four calls into a single data stream for modulating a transmitter. However, the data of each call is included in two of the data streams. Each of lines 22, from the interface 11 to the modulator/power amplifier system 13, carries one of these data streams. The modulator/power amplifier system 13 comprises a carrier generator and a modulator for each of the sub-bands b_{11}, b_{12} ,b_{13}, b'_{11}, b'_{12}, b'_{13}. The modulator outputs are amplified and supplied to the feed units 14, 15, the signals in sub-bands b_{11}, b_{12}, b_{13} going to the first feed unit 14 and the signals in sub-bands b'_{11}, b'_{12}, b'_{13} going to the second feed unit 15. The feed units 14, 15 each include power combiners for combining the signals from the modulator/power amplifier system 12 and a circulator for isolating the demultiplexer 17 from the combined signal and directing the combined signal to the respective antenna 20, 21.

The timing of the TDMA bursts generated by the the modulator/power amplifier system 12 is controlled by the controller 19. The bursts must be timed so that they reach the intended UT 5 in the correct positions within the TDMA frame, regardless of the route taken, i.e. via the first satellite 3 or the second satellite 4.

The signals radiated from the first antenna 20 are relayed to the UT 5 by the first satellite 3 and the signals radiated from the second antenna 21 are relayed to the UT 5 by the second satellite 4.

The UT 5 transmits back to the SAN 1 via only one of the satellites 3, 4. However, the SAN 1 does not know which route will be used in advance.

The signals received by both antennas 20, 21 are routed by the circulators in the feed units 14, 15 to the demultiplexer 17. The demultiplexer 17 comprises a plurality of receivers tuned repectively to sub-bands b_{21}, b_{22}, b_{23}, b'_{21}, b'_{22} and b'_{23}. Six data streams containing the data received in respective sub-bands b_{21}, b_{22}, b_{23}, b'_{21}, b'_{22} and b'_{23} are output by the receivers.

The demultiplexer outputs are applied to the signal processing unit 18. The signal processing unit 18 extracts the data from the slots in the data streams, decodes it and produces a BER value for each slot. The BER values for the corresponding slots of each link pair are compared (an empty slot will generate a very large BER value) and the decoded data from the slots having the lower BERs are output to the interface 11.

The interface 11 reformats the data from the signal processing unit 18 into packets from transmission, via the high-speed terrestrial network and the public network, to the relevant parties.

The restrictions on the bandwidth available for mobile telephone systems mean that a service operator must carefully balance the competing requirements of capacity and link quality. Users will become disillusioned if they find that they cannot make calls at will or if the speech quality is poor. The ability to make calls at will is generally more important to users than speech quality. The purpose of the present invention is in part to maintain speech quality by minimizing lost frames. However, in the embodiment described above, this is achieved at the cost of halving the capacity of the mobile telephone system.

A second embodiment will now be described, in which diversity is employed to maintain speech quality until the user demand reaches a threshold level, whereupon speech quality is sacrificed in favour of expanding the capacity of the system.

Referring again to Figures 1 to 5, during periods of low demand the SAN communicates with UTs as described above. However, if the demand increases to a threshold level, for example when 5% of attempted connections using the link between the SAN 1 and the UT 5 cannot be made because of lack of available channels, the network control systems issue a command to the SAN 1 to cause it to switch to a conventional mode of operation. The SAN 1 passes on this command to each of the UTs 5 which are registered with it. In the conventional mode of operation, each channel makes use of a single satellite 3, 4.

In response to this command, the UT 5 ceases to compare BERs for link pairs and listens to only one band-slot, for example b_{12}-t_3. The band-slot in which the UT 5 transmits is determined on the basis of the receive band-slot and a channelization scheme, and may be, for example, b_{22}-t_1. The same satellite, e.g. the first satellite 3, is used for communication both to and from the UT 5.

The SAN 1 of this embodiment is substantially the same as that described above with reference to Figure 5. However, its operation is somewhat different.

As in the case of the UT 5, the SAN 1 operates as in the first embodiment until it receives a command from the network control systems. In response to this command, the controller 19 instructs the interface 11 to apply the data for each call to a single time slot in only one of the data streams.

Under the control of the controller 19, the signal

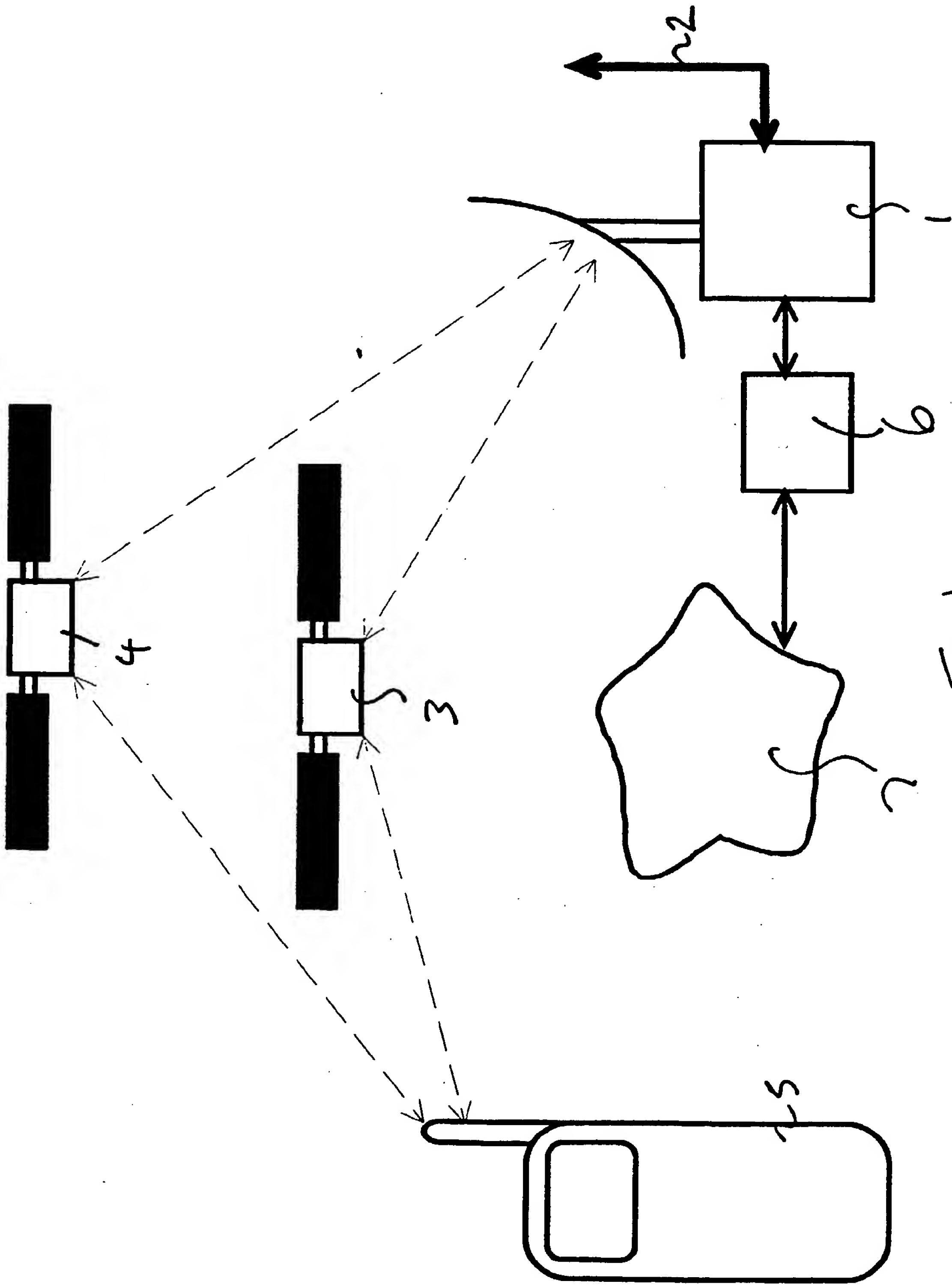

Fig.1.

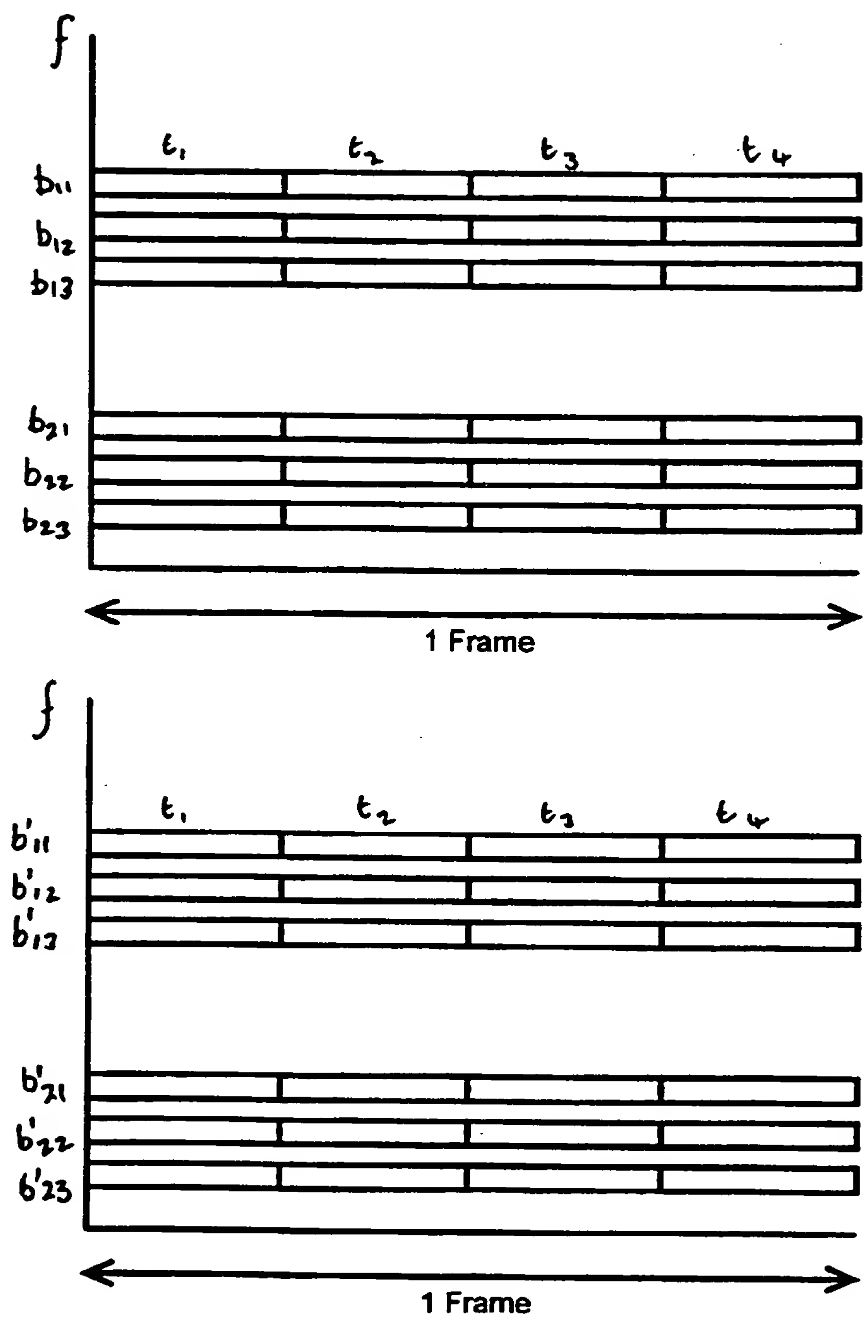
f
t1
t2
t3
t4
b11
b12
b13
b21
b22
b23
1 Frame
f
t1
t2
t3
t4
b'11
b'12
b'13
b'21
b'22
b'23
1 Frame

Fig. 2.

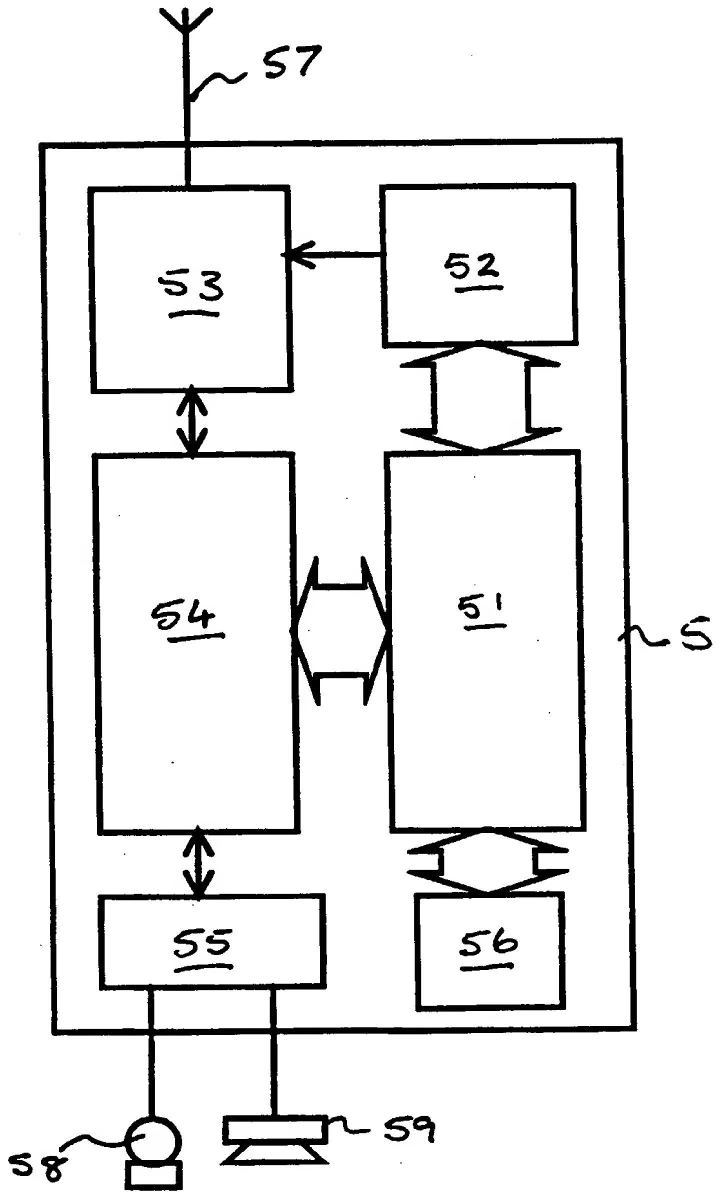

Fig. 3.

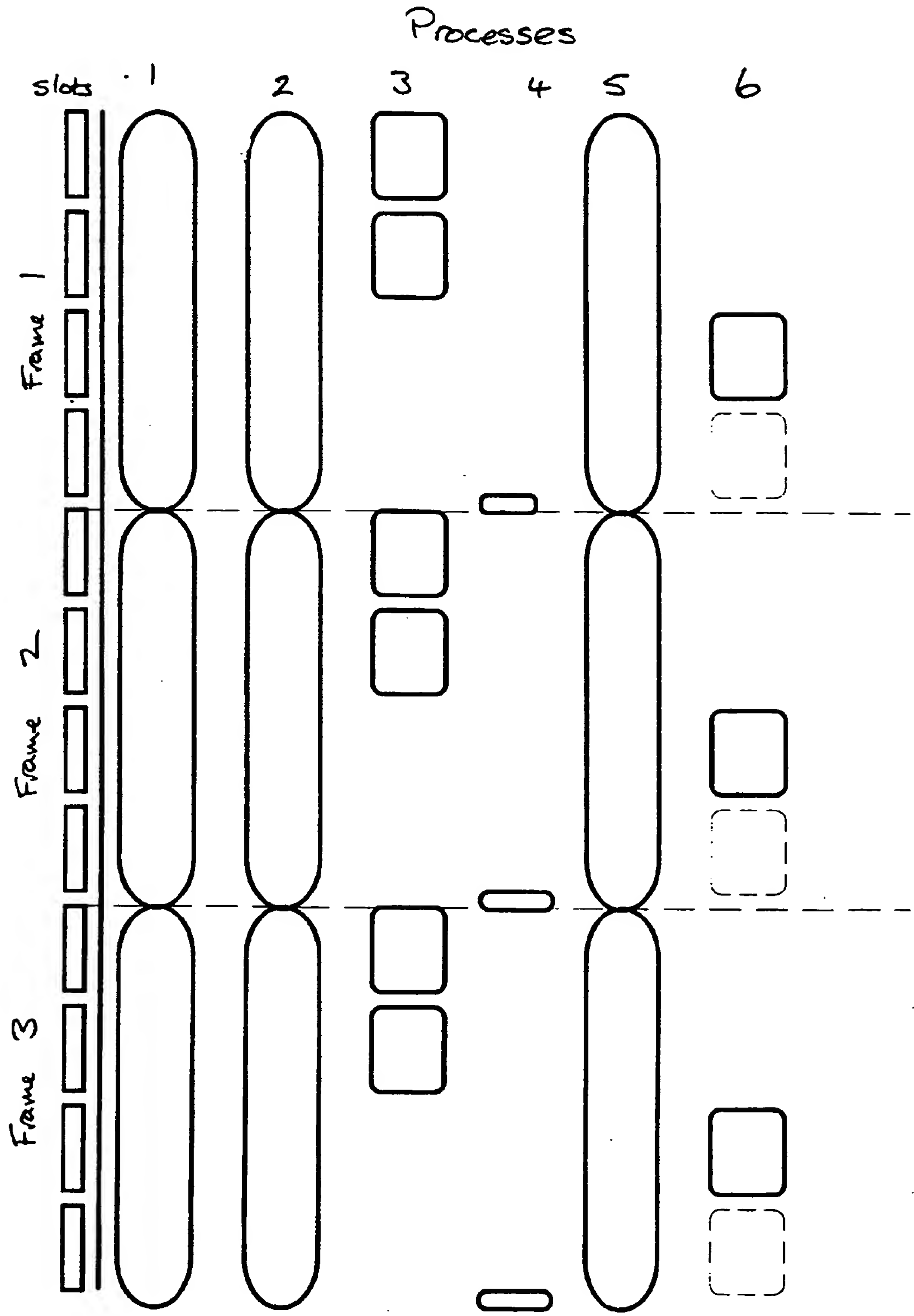

Fig. 4.

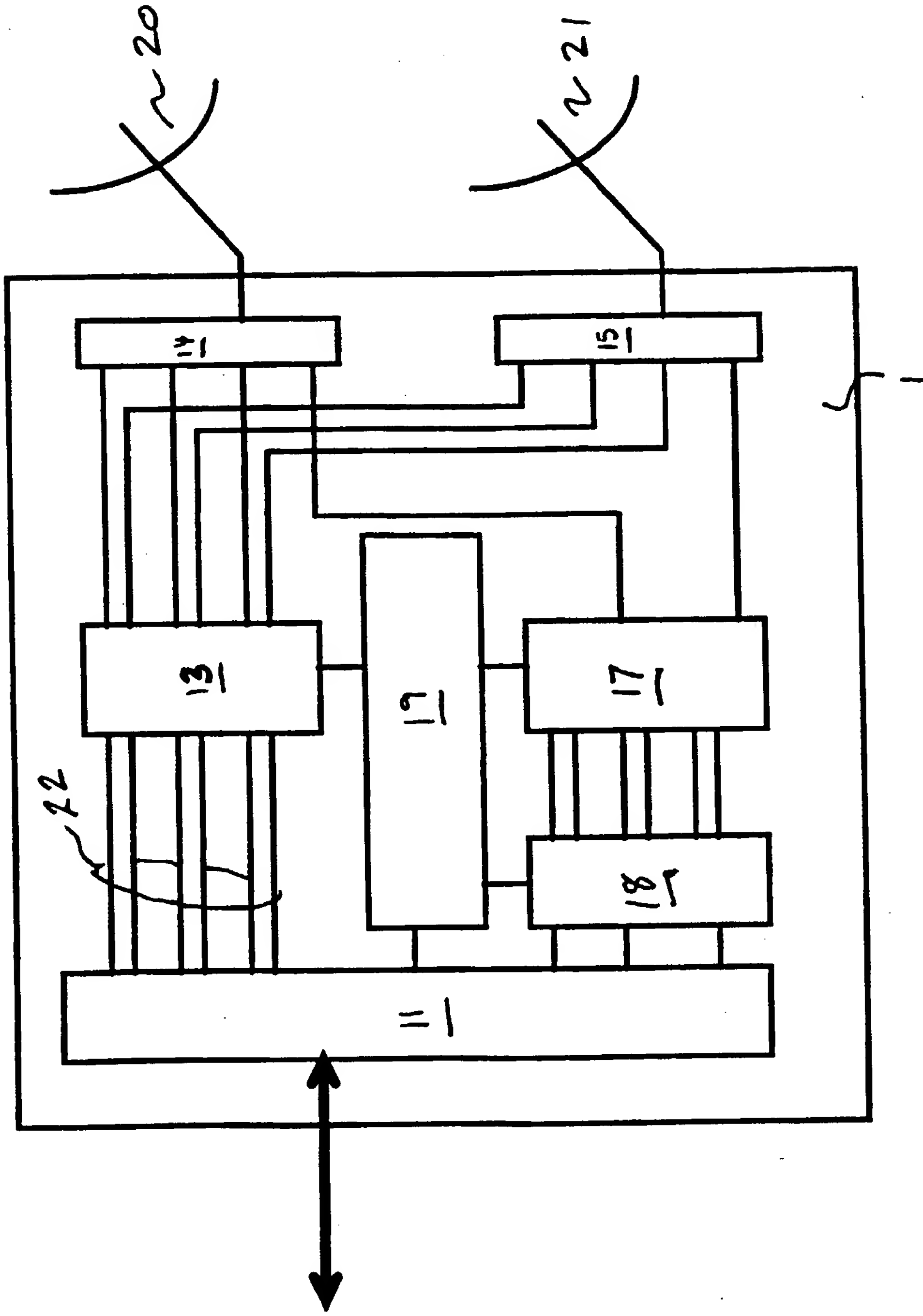

Fig. 5

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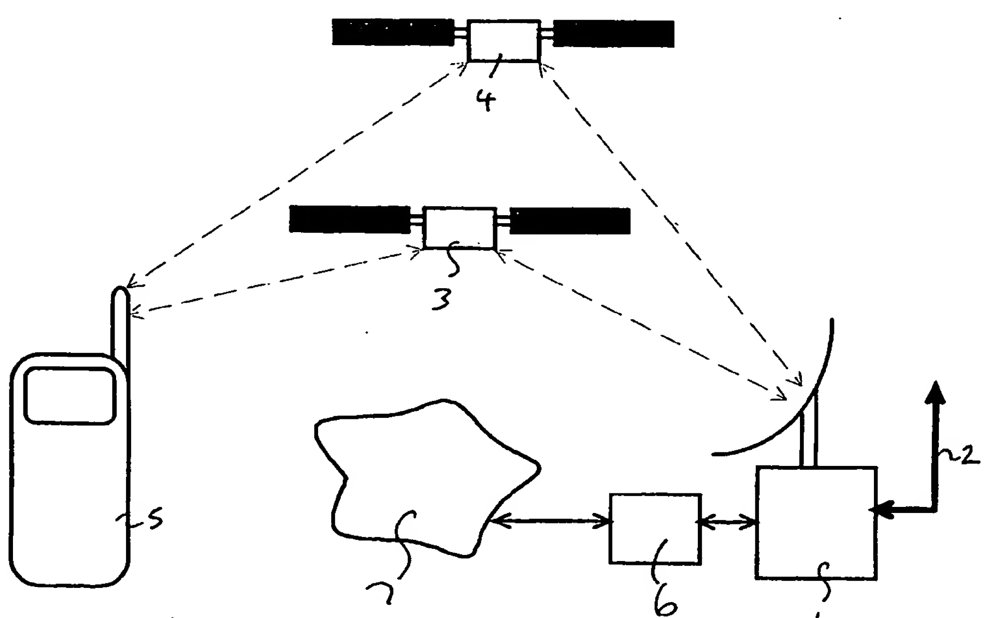

Fig. 1.

EP 0 837 568 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 30 8094

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	EP 0 682 416 A (LORAL QUALCOMM SATELLITE SERVICES) 15 November 1995 * claims 1-30 * ---	1-17	H04B7/185
X	EP 0 288 904 A (MOTOROLA) 2 November 1988 * page 2, line 40 - page 3, line 15 * ---	1,2,5-15	
X	US 5 487 174 A (PERSSON) 23 January 1996 * column 4, line 41 - column 5, line 43 * ---	1,2,5-15	
X	US 5 309 503 A (BRUCKERT ET AL.) 3 May 1994 * claims 1-23 * ---	1,2,5-15	
X	WO 87 03441 A (TANDEM) 4 June 1987 * claims 1-7 * ---	1,10	
A	EP 0 748 065 A (GLOBALSTAR) 11 December 1996 * claims 1-39; figures 1-11 * -----	1-17	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			H04B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	16 October 1998	Bischof, J-L

CATEGORY OF CITED DOCUMENTS

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